Jet Propulsion Laboratory
California Institute of Technology

RAMS 2018

B. John Garrick Institute for the Risk Sciences
UCLA ENGINEERING

COTS Electronics in Space
- COTS Technology Panel -

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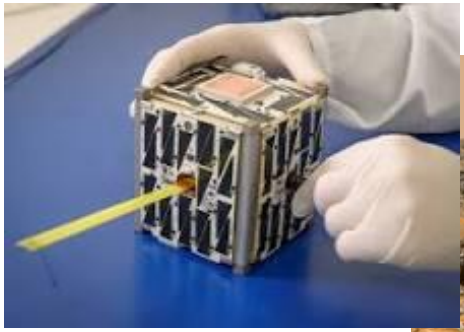
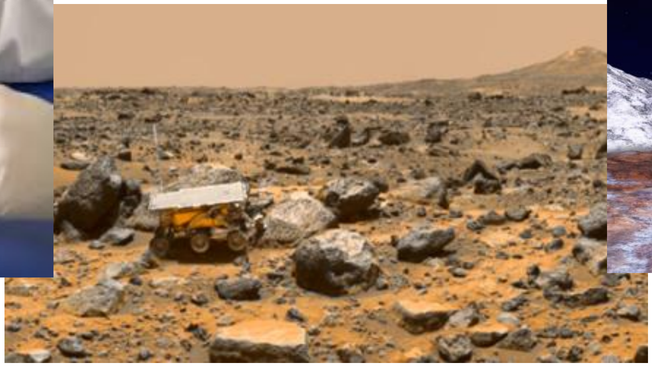
The Big Picture

- NASA has been directed to develop a plan for an innovative and sustainable program of exploration with _commercial_ and international partners to enable human expansion across the solar system, returning humans to the moon for long-term exploration and utilization, followed by human missions to Mars and other destinations.
- While it remains unclear what role JPL will play in this vision, the use of COTS H/W in our missions will become more commonplace.
- It is imperative we continue to study and understand the risk of inserting COTS technologies into our hardware.





Modeling for COTS Electronics in Space Systems

Space systems designs are trending towards using ever more high commercial performance electronics

Commercial electronics represent an ever higher fraction of a system's part inventory

Testing parts for every part type will be too costly and not practical

➡ Modeling practices to support "virtual assessment" from part to system

Rad Models

JPL COTS System

Uncertainty Quantification Methods

Part to System Flow

System level performance

System trades

JPL experimental V&V of Models

<u>Anticipated results</u>

First development of a "virtual assessment modeling framework" for Commercial-Off-The-Shelf (COTS) systems

New process development within 5X that will benefit JPL missions

<u>Applications:</u>

Short term: Sub-systems and systems
Long term: JPL CubeSats/SmallSats/Class D

A strategic long term partnership

JPL is leveraging simulation capabilities investment at SNL

SNL updates own tools to accommodate JPL care-abouts

SNL lacks our system level reliability trades capabilities

SNL is funded to support this collaboration

Joint product: Transistor to Spacecraft Reliability

High-Level Goals

- Aid design decision throughout the project life cycle
- CubeSats provide the initial test cases, Class B missions are the future targets
- Tailor model fidelity to project risk posture and design maturity
- Low fidelity models:
  - not quantitative and use generic and/or best guess reliability information
  - comparative to support system architecture studies and fault protection
  - informing the user of key risk drivers
  - very fast! Spacecraft models created in weeks. Scenarios executed in minutes.
  - most likely users are proposals teams, system engineers
- High fidelity models:
  - are multi scale and have the ability to model piece parts and entire spacecraft
  - use test data, physics based simulation results, lookup tables, heuristics, etc.
  - are quantitative and estimate level of confidence (UQ, Monte Carlo, …)
  - most likely users are reliability and radiation specialists at JPL
- Provide an integrated framework for reliability estimation of COTS devices considering both qualitative and quantitative information, when little or no test data are available.

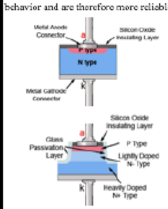
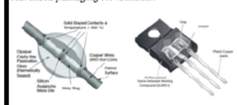
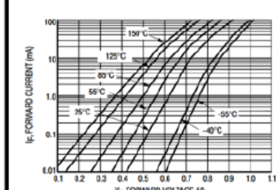
JPL COTS Parts Risk & Reliability User & Application Guide

- **JPL Guideline:** 'Commercial Off-The-Shelf (COTS) Parts Risk & Reliability User & Application Guide' (Dec. 2017)
  - ***Screening at higher levels of assembly (PCB, System Level) will become more prevalent with the infusion of the latest COTS parts.***
    - Scaling trends and reliability concerns for different CMOS applications
    - Effect of processing variations on reliability
  - *For many VLSI/ULSI devices, particularly those optimized for speed, the junction temperature must be restricted to lower ranges than for previous generations and technology nodes.*
  - *Raising the burn-in temperature may not only be risky, but may also increase the chance of inadvertent thermal runaway during burn-in.*
  - *It is also possible for undetected transients during burn-in to damage good devices, increasing the chances of "walking wounded" devices being used in the flight lot.*
  - *Where part level testing is not possible, board level testing and/or system level testing may be the only alternative. In such cases, critical functional specifications should be tested and verified.*
  - *For advanced technologies, derating voltages below the manufacturer's prescribed level may render the device inoperable.*

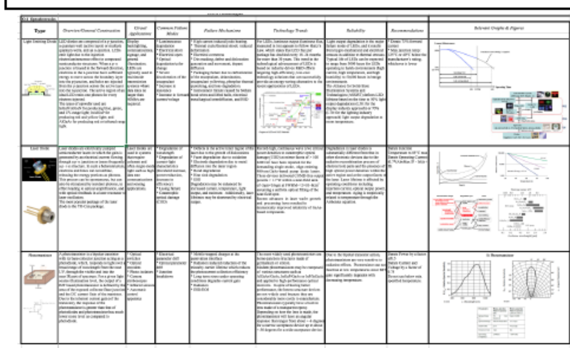
JPL COTS Parts Risk & Reliability
User & Application Guide – Excel-Based Appendix

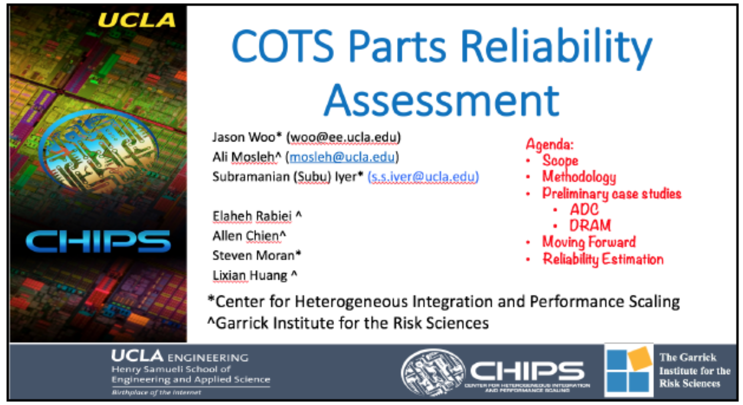
- **Created an Excel-based Appendix** consisting of 30 examples of EEE Parts addressing reliability and risk factors
  - Caps, Diodes, Optoelectronics, Microcircuits, Resistors, Thermistors, Transistors

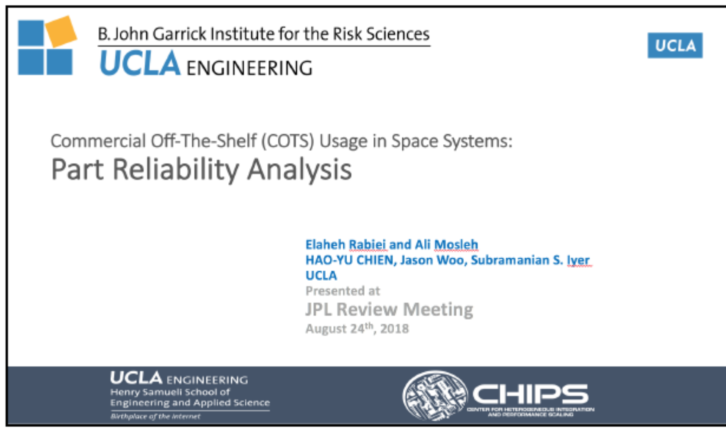
  - Part Type
  - Overview/General Construction
  - Circuit Applications
  - Common Failure Modes
  - Failure Mechanisms
  - Technology Trends
  - General Reliability
  - Recommendations for operation

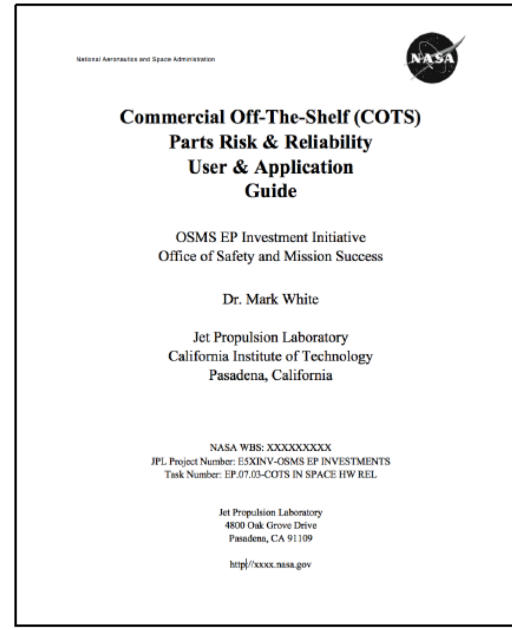
D-1 Diodes								
Type	*Overview/General Construction*	*Circuit Applications*	*Common Failure Modes*	*Failure Mechanisms*	*Technology Trends*	*Reliability*	*Recommendations*	*Relevant Graphs & Figures*
Rectifier Diode	Rectifier diodes can handle higher current flow than regular silicon diodes and are generally used in order to change alternating current into direct current. They are designed as discrete components or as integrated circuits and are usually fabricated from silicon and characterized by a fairly large P-N-junction surface. This results in high capacitance under reverse-bias conditions. In high-voltage supplies, two rectifier diodes or more may be connected in series in order to increase the peak-inverse-voltage (PIV) rating of the combination. ***Planer diode structures*** Substrate diode Well diode Epi diode 	Mainly used to convert AC to DC. Used to regulate power in computers and the electrical power in motor vehicles. Also, used in battery chargers for rechargeable batteries, computer power supplies and vehicle batteries.	• Thermal runway • Increase in leakage current • Reduction in reverse breakdown voltage • Open circuit • Short circuit	• Excessive power dissipation due to EOS (electrical over stress) • ESD • Degradation of passivation oxide	Mesa diode construction has better electrical behavior and are therefore more reliable. 	Diodes will experience displacement damage and ionizing damage in severe radiation environments, which can cause significant increases in reverse current. However, diodes show very little functional detriment up to about 10 kRads 50 to 100. Advanced packaging for rectifiers: 	Industry standard derating for 10-yr reliability: • Maximum Tj = 0.75 (Tjmax - 25°C) + 20°C -*Forward Current ≤ 80% Reverse Voltage ≤ 70% Power ≤ 75%	

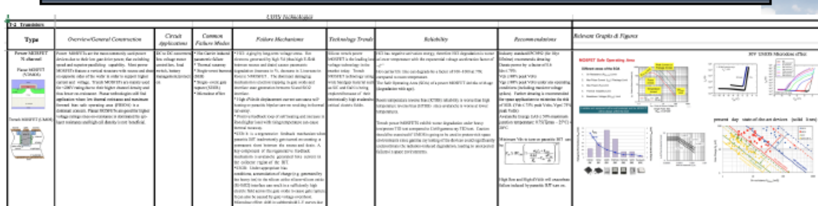
UCLA Partnership

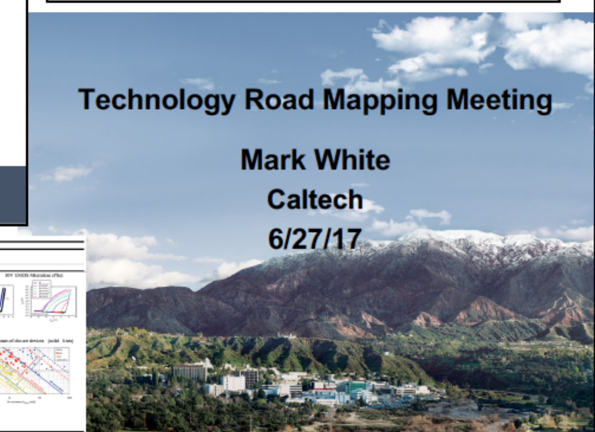






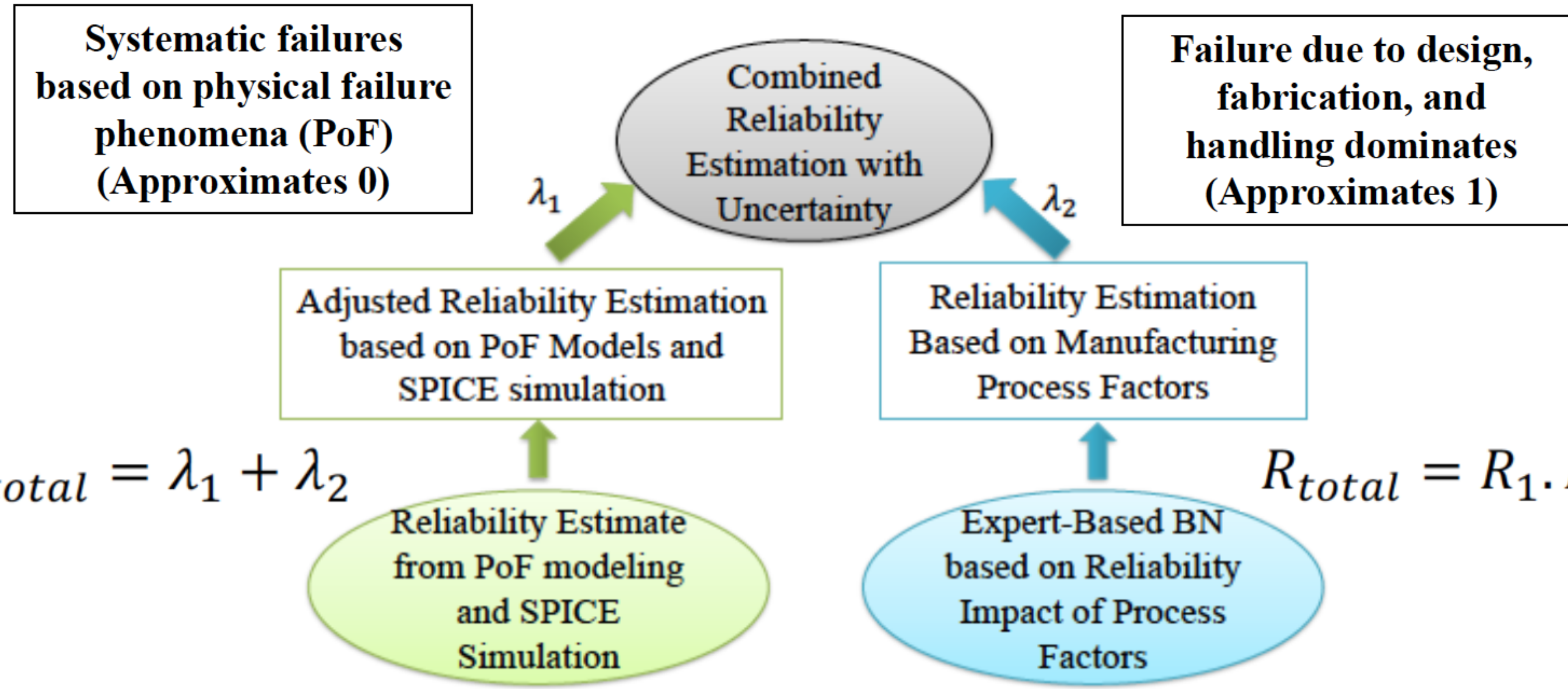






Combined Reliability Estimation and Uncertainty

COTS Reliability Estimation based on Two Main Types of Contributing Factors



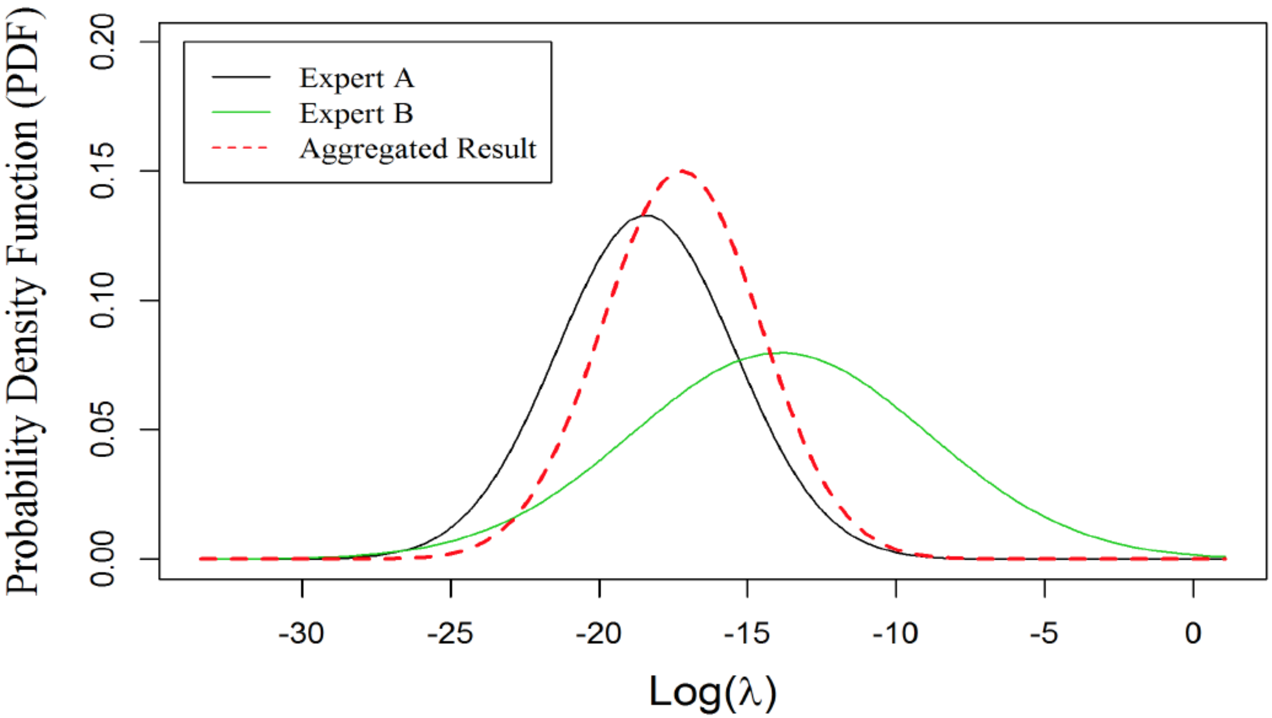
$$\lambda_{total} = \lambda_1 + \lambda_2$$

$$R_{total} = R_1 . R_2$$

IC failures are likely to be due to random defects introduced during the manufacturing of the chips or during packaging and handling instead of wearout

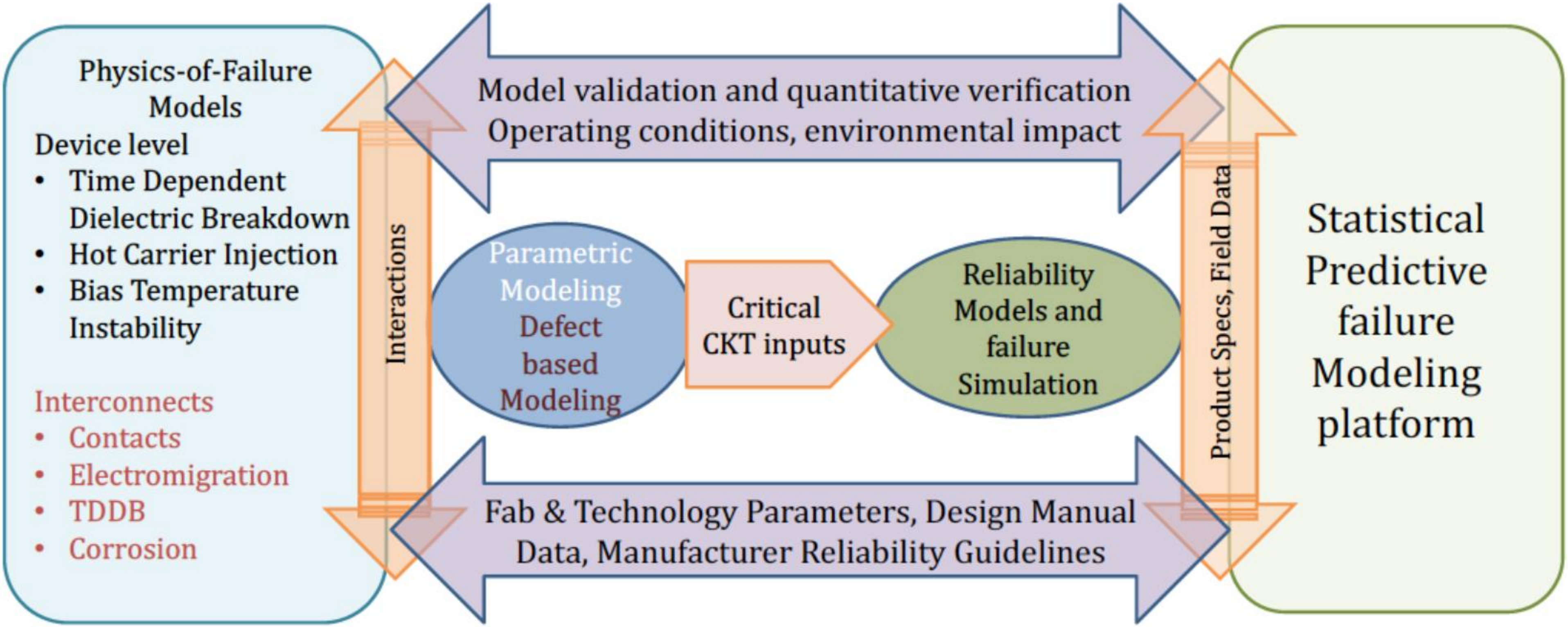
Simulation Tools

- **Simulation Tool:** Developed initial version of R-based simulation tool to model PDF / Shape of Expert Opinion inputs based on semiconductor Process, Fab, Product & Design Factors
  - Given Expert input 1-n
  - S/W provides Aggregate Distribution



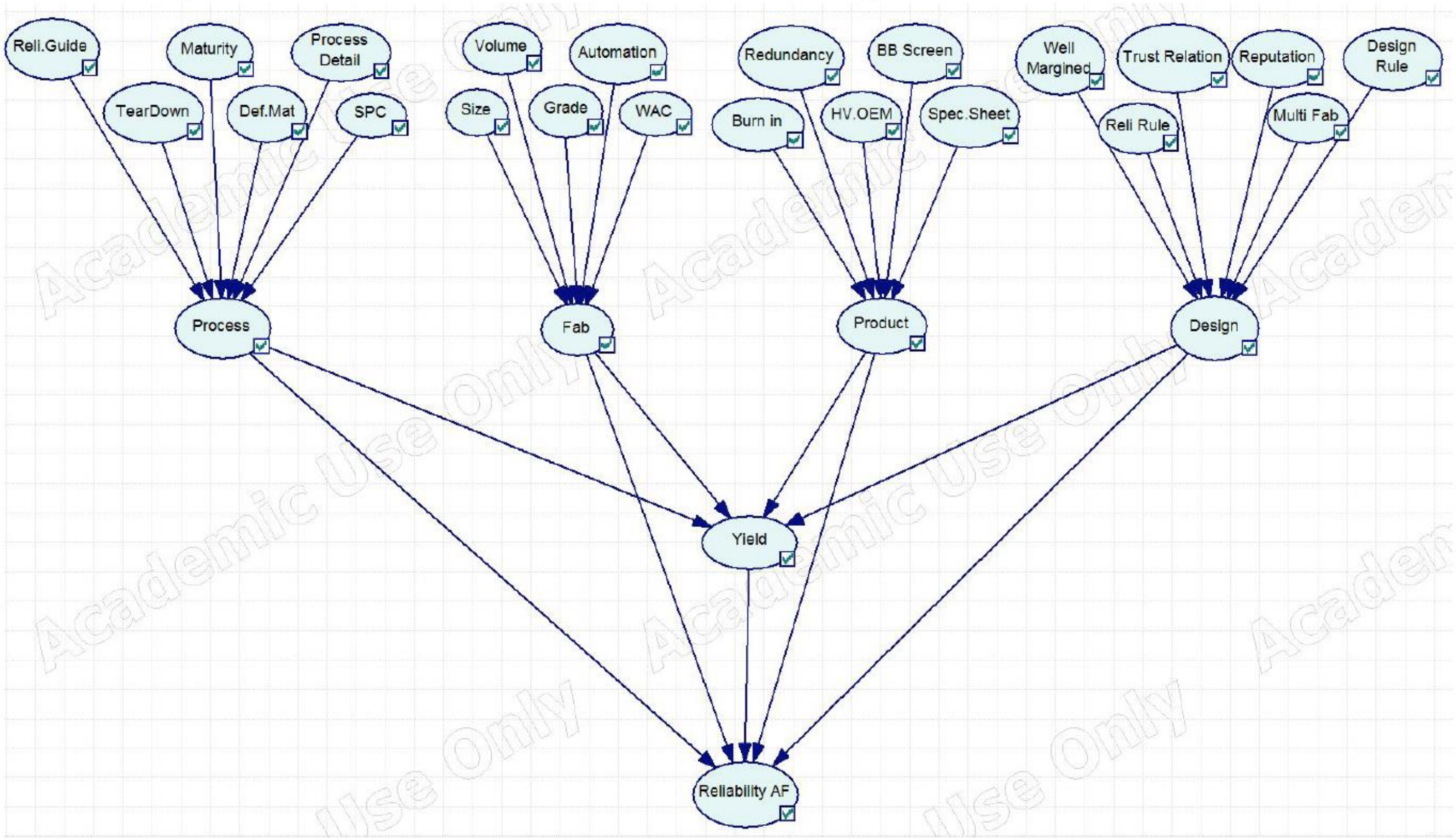
Bayesian Posterior Distribution of Failure Rate based on Fusion of Expert Estimates

Device-Level Methodology

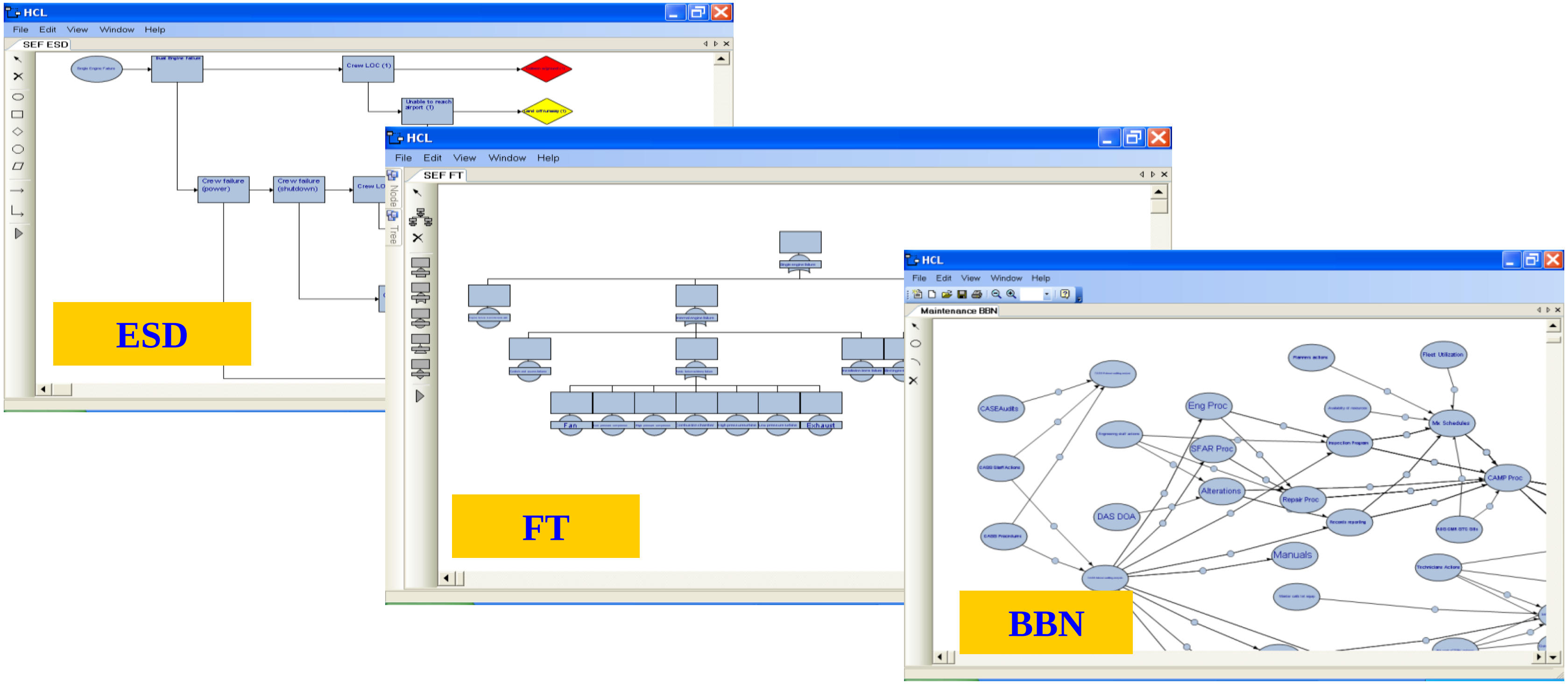


Expert-Based Bayesian Network

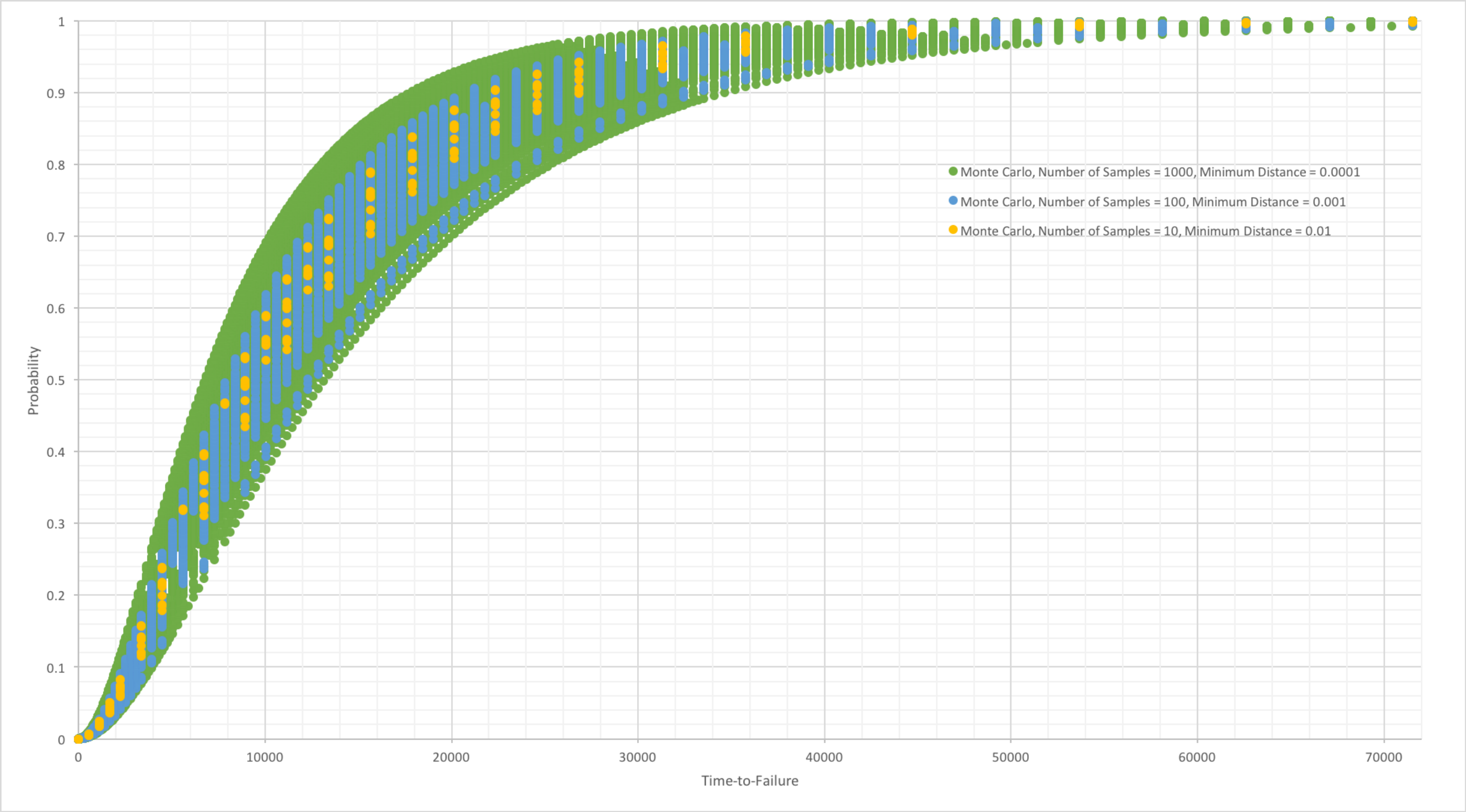
When the Bayesian network model is fully defined by field experts, the analyst can apply it to a particular manufacturer and part of interest by selecting the states of each node with regard to its characteristics.



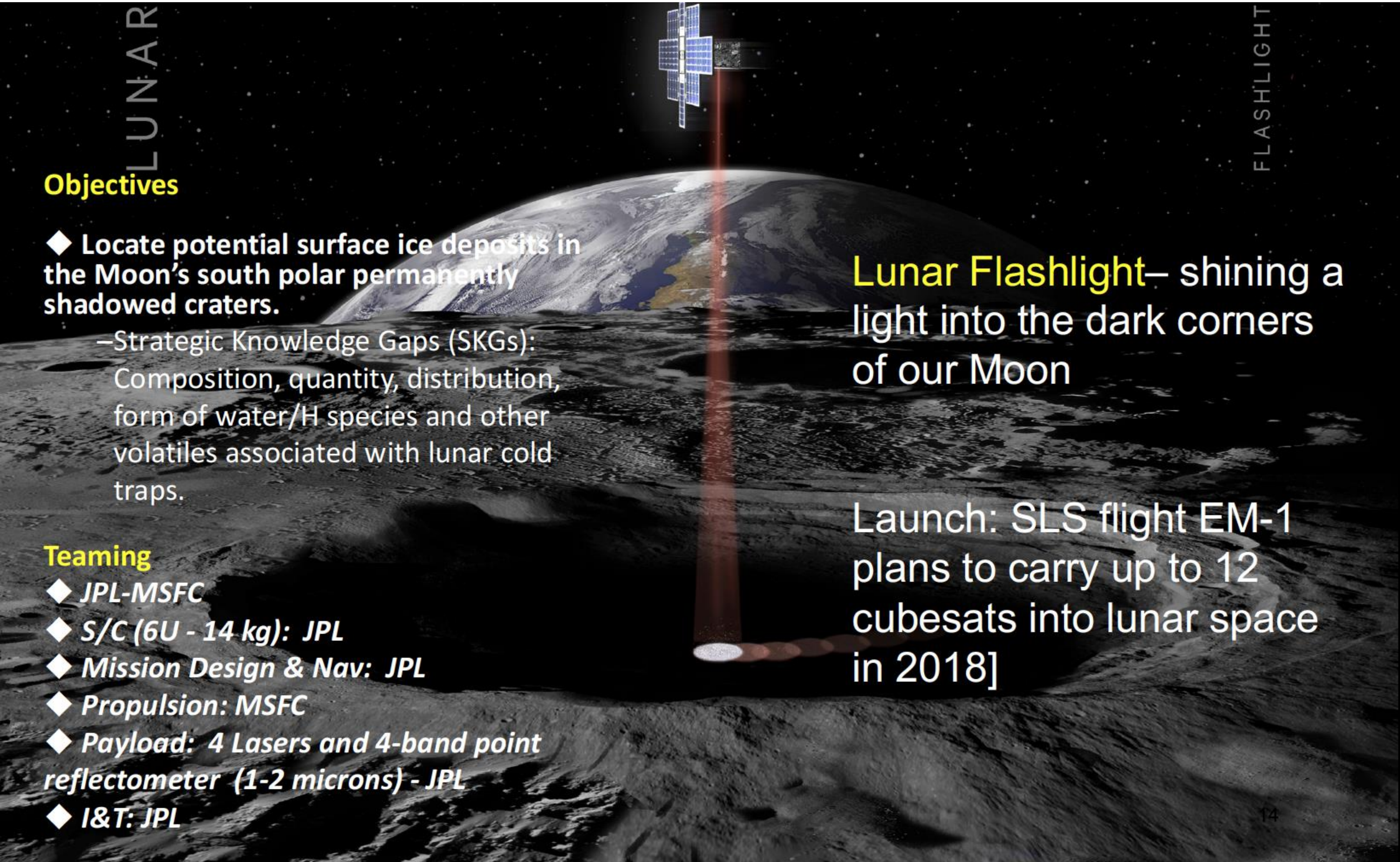
COTS System-Level Reliability
IRIS Logic Modeling Capability



Time-to-Failure Propagation with Parameter Uncertainty (Simulated)



Lunar Flashlight Mission Overview



Objectives

- **Locate potential surface ice deposits in the Moon's south polar permanently shadowed craters.**
  - –Strategic Knowledge Gaps (SKGs): Composition, quantity, distribution, form of water/H species and other volatiles associated with lunar cold traps.

Teaming

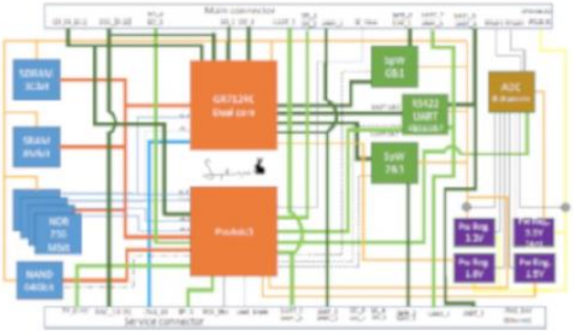
- ***JPL-MSFC***
- ***S/C (6U - 14 kg): JPL***
- ***Mission Design & Nav: JPL***
- ***Propulsion: MSFC***
- ***Payload: 4 Lasers and 4-band point reflectometer (1-2 microns) - JPL***
- ***I&T: JPL***

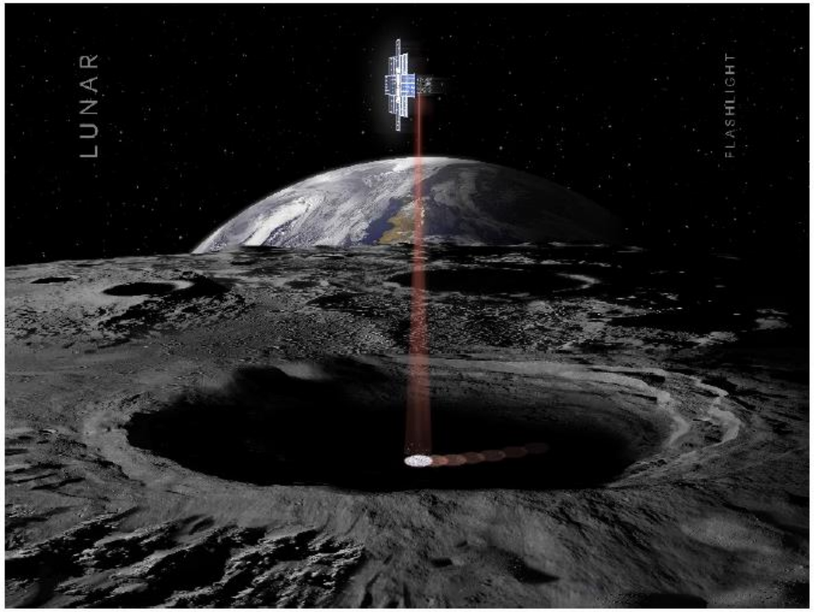
Lunar Flashlight– shining a light into the dark corners of our Moon

Launch: SLS flight EM-1 plans to carry up to 12 cubesats into lunar space in 2018]

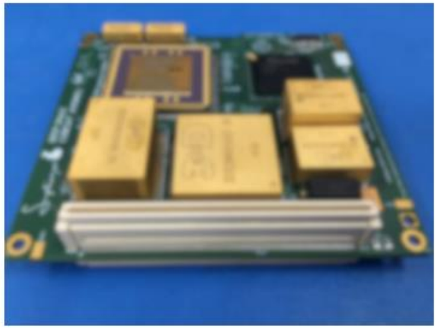
Test Case: Lunar Flashlight C&DH

- **Objective to exercise and validate models**
- **Small part list and simple design makes problem tractable**
- **Engineering models will be used for reliability and radiation testing**
- **Eventual flight will provide additional validation**





Lunar Flashlight (6U)
NIR laser



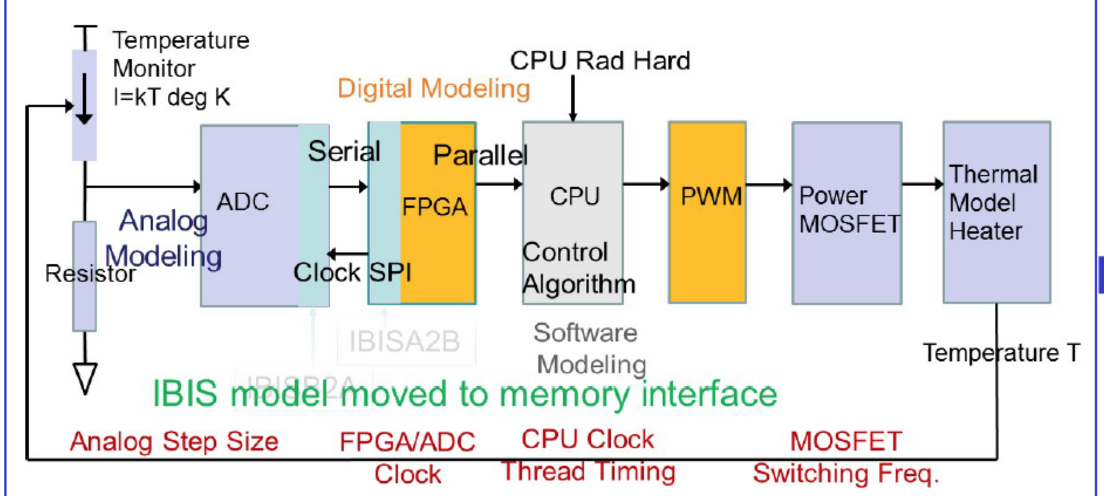
Anticipated Results

First development of a "virtual assessment modeling framework" for COTS systems

=> *New process development within 5X that will benefit JPL missions*

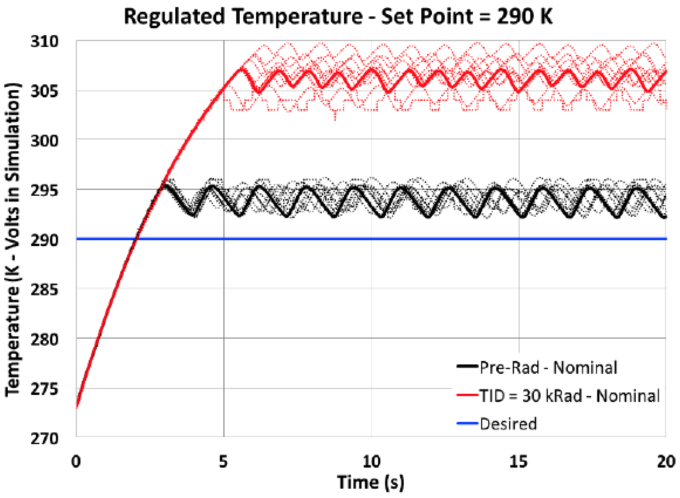
Example of modeling flow developed

Temp. control loop within Sphinx C&DH



Radiation modeling embedded in parameter variation

Closed-loop simulation results

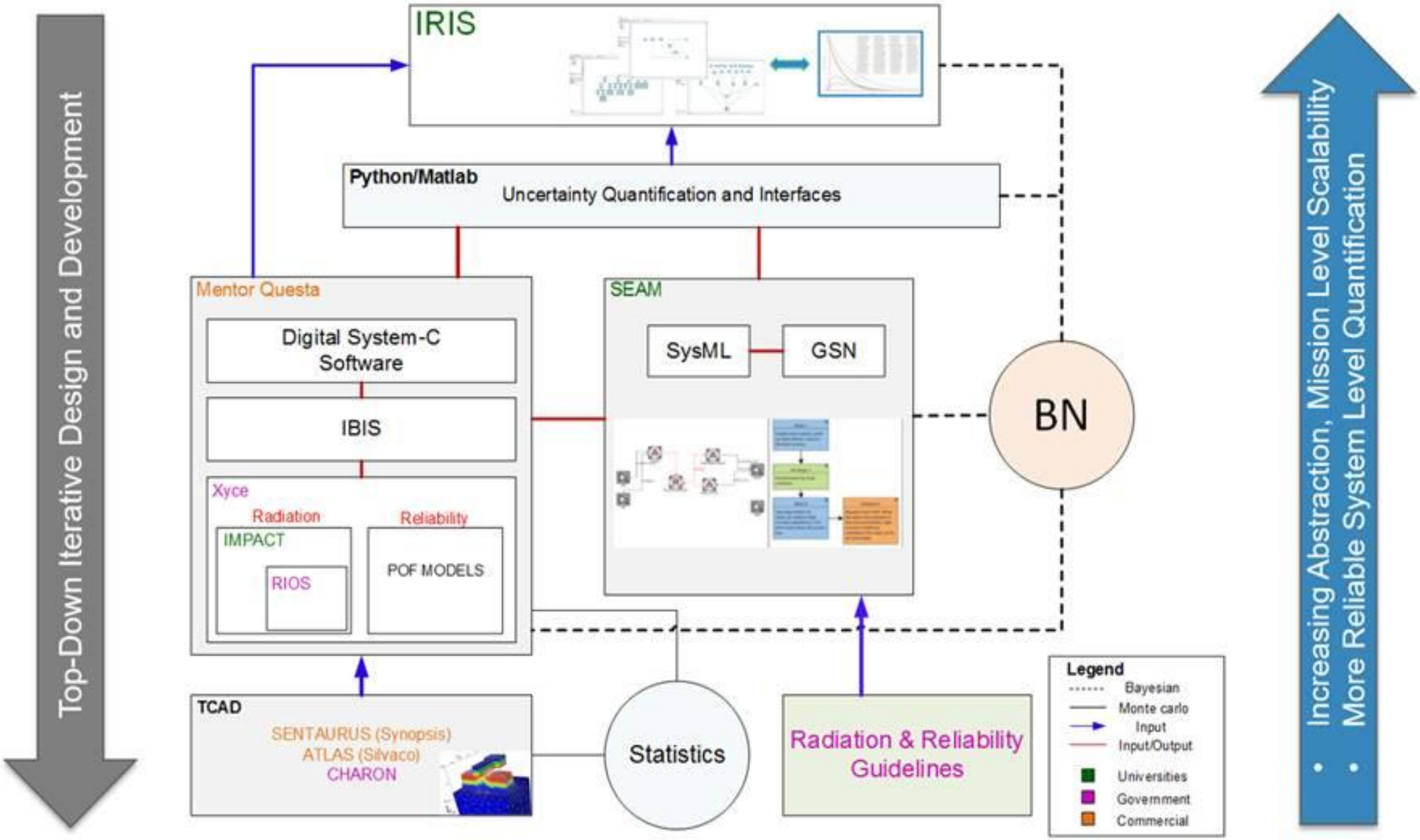


Monte Carlo analysis included

Modeling Tools
(Notional)

Abstraction	Domain	Domain Specific Tools	CrossCut Tools					
			Python	Matlab	Dakota	Questa	IMPACT	MRED
H	System/Requirements	SysML						
	Functional	Orchestra (SNL) SysC						
	Behavioral	IBIS						
	Circuit	Xyce (SNL) Gateway X-SPICE Cadence						
L	TCAD	Charon (SNL) Atlas (Silvaco) RIOS (SNL) Sentaurus (Synopsis)						
					SNL	VU	ASU	VU

Modeling Tool Integration
(Proposed)



In Summary

- NASA has used commercial parts successfully in spacecraft, including mission critical applications. In the past, this was achieved through meticulous selection, screening and qualification.
- Alternative methods must be developed to assure low risk and sufficient reliability for the mission application.
- The development of modeling tools and a framework are becoming paramount in the evaluation of COTS-based Spacecraft Systems - *Virtual Qualification:*
  - Transistor
  - Component
  - System